Modeling and Analyzing Budget Constrained Pavement Preservation Strategies

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ABSTRACT

The Washington State Pavement Management System (WSPMS) has a long and well known history of describing network condition, predicting necessary rehabilitation and guiding the Washington State Department of Transportation (WSDOT) to the best possible value for pavements meeting an acceptable Level of Service (LOS). By definition, Lowest Life Cycle Cost (LLCC) is the most economical way to manage roadways to a required LOS. What does an Agency do when it is currently, and projected to be, funded at less than half of what LLCC calculations recommend? This is a deceptively difficult question and the situation WSDOT currently faces with its preservation budget. To assist the agency in answering this question, a Forecaster has been developed within the WSPMS that allows definition of a Forecast Scenario that allows the user to define yearly budget with optional allocations, preservation techniques, prioritization of roadways and activities, and more, and analyzes the results of the forecast using several different performance measures. This paper provides an overview of (a) the new WSPMS tool to create forecasts, (b) a general overview of the forecast process, and (c) the performance measures WSPMS presents for users to analyze the results of a forecast. Finally, several funding scenarios are compared by the expected performance measure outcomes and a specific prioritization methodology is recommended for the severely constrained WSDOT preservation budget.

List of Abbreviations and Acronyms

Some of the terminology used throughout this paper necessitates a number of abbreviations and acronyms. This section is included as a quick reference.

- $/LMT – Dollars per Lane Mile Truck
- AADT – Annual Average Daily Traffic
- ACP – Asphalt Concrete Pavement
- EFF – Equivalent Failure Factor
- EUAC – Equivalent Uniform Annual Cost
- JPCP – Jointed Plain Concrete Pavement
- LCCA – Life Cycle Cost Analysis
- LLCC – Lowest Life Cycle Cost
- LMY – Lane Mile Years
- LOS – Level of Service
- NHS – National Highway System
- PRR – Preservation, Restoration and Reconstruction
- RSI – Remaining Service Indicator
- RSL – Remaining Service Life
- VMT – Vehicle Miles Traveled
- WSDOT – Washington State Department of Transportation
- WSPMS – Washington State Pavement Management System
- 60-10-30 – A funding allocation of 60% ACP, 10% chip seal, and 30% JPCP

BACKGROUND

Economic conditions in the last five years have created circumstances that have made management of pavement assets very difficult. Most state and local transportation agencies have been severely impacted by budget reductions, while the costs of maintenance and construction have not decreased significantly. The outlook for pavement asset management remains uncertain, with continued funding shortfalls for transportation agencies expected into the future.

This environment has led WSDOT to investigate the impact of severe funding limitations on the management of the state's road network. As discussed later in this paper, managing a transportation asset at the Lowest Life Cycle Cost (LLCC) requires a certain level of investment. If that level of investment is not available, then what decisions should be made in order to manage the system at the best (although sub-optimal) level possible?

To frame this evaluation, the pavement management objectives need to be clearly defined and examined by comparing against performance measures:

a) <u>Provide a safe, functional, and efficient pavement network.</u> The road users (and taxpayers) should be provided with a network of roads that provide the best possible travel for people and goods.
   - Performance measures: Pavement condition and risk.

b) <u>Protect the infrastructure asset</u>. The public has made investments over many years to build an important transportation infrastructure. This investment must be protected and managed with good stewardship.
   - Performance measures: Remaining Service Life (RSL), Asset Sustainability Ratio and Equivalent Failure Factor

c) <u>Manage the network in a sustainable, cost-effective manner</u>. Maximize the benefits obtained from resources and minimize costs.
   - Performance measures: Annual Expenditure by Activity, Deferred Preservation Liability, Asset Sustainability Ratio and Equivalent Failure Factor.

Given these objectives a methodology was developed to prioritize resource allocation for severely constrained budgets by examining the performance measures and evaluating which decisions lead to the best (sub-optimal) results. The methodology can be validated and adjusted by monitoring these important performance measures over time.

INTRODUCTION TO METHODOLOGY

By definition, the best way for an agency to manage its assets while providing an acceptable Level of Service (LOS) is through LLCC. Therefore, much research and effort has been put into Life Cycle Cost Analysis (LCCA), which directs pavement management practitioners to preservation strategies that implement LLCC *(1)*. For flexible pavement, either Asphalt Concrete Pavement (ACP) or Bituminous Surface Treatment (Chip Seal), the LLCC strategy is to extend the life of the pavement wearing course as long as possible without letting significant damage to the underlying pavement structure occur, followed by a resurfacing. For rigid pavement (solely Jointed Plain Concrete Pavement (JPCP) in Washington) the strategy is to extend the life of the pavement as long as possible. Common rehabilitation practices for WSDOT rigid pavements include diamond grinding and dowel-bar retrofit. At the end of pavement life reconstruction is often necessary, or conversion to a flexible pavement structure. WSDOT uses site specific LCCA to determine the most appropriate preservation strategy for each section of roadway.

LCCA allows the three main surface types (ACP, chip seal and JPCP) to compete for the most effective life-cycle cost strategy. For lower volume roadways (WSDOT currently uses

5,000 AADT or less as a policy), chip seal tends to have the LLCC. For sections with moderate to high levels of traffic without special configuration or traffic considerations (such as in downtown Seattle), ACP has the LLCC. Finally, for sections with very high traffic, special configuration considerations or in mountainous environment conditions, JPCP has the LLCC.

Based on the average time between major LLCC treatments (i.e. resurfacing for flexible pavements and grinding/panel replacement/reconstruction for JPCP), average major LLCC treatment costs, and assuming that the proper pavement design is used in each section, a simplified annual cost for LLCC management of the entire network can be calculated as the sum of the LLCC for each appropriate LLCC activity, or:

$$Annual\ LLCC\ Funding = \sum_{LLCC\ Activities} \left(CLM \times \frac{1}{TBA} \times LM\right) \tag{Eq. 1}$$

WHERE (at LLCC): *CLM = Construction Cost Per Lane Mile of the Activity*
TBA =Time between Activity (in years)
LM = Lane Miles of Activity Appropriate Roadways (in Network)

This calculation gives a reasonable estimate for the annual funding necessary to manage a network of roadways while implicitly meeting an acceptable LOS. For the purpose of this analysis, full LLCC funding is considered the "Baseline" scenario against which other scenarios will be compared. In the process of evaluating the outcomes of budgets with less than adequate funds, and keeping the pavement management objectives in mind, the following questions develop:

- How are LLCC needs prioritized if there is insufficient funding to complete all of them?
- Should non-LLCC activities take precedent over LLCC activities, based on the criticality of the roadway?
- What funding strategy offers the best LOS over the short-term? Over the long term?
- What performance indicators should be used when comparing prioritization strategies?

To help the Washington State Department of Transportation (WSDOT) answer these questions, a new pavement asset forecasting tool was developed for the Washington State Pavement Management System (WSPMS), referred to as the Forecaster.

THE FORECASTER IN THE CONTEXT OF THE WSPMS

As the Forecaster is part of the WSPMS, it is relevant to introduce some WSPMS terminology and functionality. The WSPMS integrates and analyzes data from throughout WSDOT, including information about contracts, planned preservation programs, traffic, lane configuration, maintenance activities, pavement condition and more. Each year a new version of the WSPMS is released, with updates made to all of these data sources, especially an update of the network pavement condition information collected the previous year. For each annual version, WSPMS segments State Roadways into 0.1 mile units, called *Survey Units*, each with homogenous surface type and surface age. For each Survey Unit, current and historical condition information is summarized based on surface distress, roughness and rutting. Regression analysis is used against the condition data to predict the optimal year for the major LLCC rehabilitation activity, called the *Due Year*. To make the number of units more manageable, a separate segmentation algorithm creates longer *Preservation Units* (typically 1 mile in length) from the Survey Units, which are homogenous for surface type and relatively homogenous for Due Year. It is these Preservation Units that the Forecaster uses in its algorithms and analysis.

Here is a list of fields that Preservation Units carry when used in the Forecaster:

1) Segment Information (Route Identifiers, Length, Lane Miles)
2) Surface Type
3) Average Surface Age
4) Due Year
5) Due Year Trigger (i.e. was it structure, roughness or rutting)
6) Annual Average Daily Traffic (AADT)
7) Percent Trucks
8) Federal Functional Class
9) WSDOT Region
10) Terrain

Additionally, other columns which are useful when creating a Forecast Scenario for a sub-network, which the Forecaster allows, include:

11) National Highway System (NHS) Indicator
12) County

CREATING A FORECAST SCENARIO

The first task of the Forecaster is defining a Forecast Scenario. The main components of the Forecast Scenario are the Funding Stream, Condition Dictionary, Rehabilitation Dictionary and Prioritization Strategy.

Funding Stream

The Funding Stream is number of years in the Forecast and the available funding in each year. The Funding Stream is not limited to a preset number of years. For each year in the Funding Stream, the total funding and an optional allocation to the three major surface types are specified. For scenarios that implement LLCC at some point, there is also an optional setting that indicates the year to start completing all LLCC designated activities.

Condition Dictionary

Major assumptions about roadway condition must be made in any forecasting model, for the Forecaster these assumptions are defined in the Condition Dictionary, and are based on Remaining Service Life (RSL). In the context of the Condition Dictionary, the RSL is allowed to be negative and is defined as the difference between Due Year and the current year in the Forecast.

It must be noted that pavement “condition” is ambiguous between public perception of roadway condition, the condition of roadway at the surface and the condition of the entire pavement structure. In the context of the Forecaster, the most important connotation is related to the entire pavement structure, since activities to replace or restore the structure are the costliest. Therefore, the Condition Dictionary uses five different terms:

- Failed – The pavement surface has been in a prolonged state of disrepair and reconstruction is necessary, generally very negative RSL (amount varies by surface type).
- Deficient – The pavement surface has been in an extended state of disrepair and structural restoration is necessary, generally negative RSL (amount varies by surface type).
- Fair – The pavement surface is at or nearing the end of its useful service life, generally about 1/3 or less RSL.
- Good – The pavement surface is in the middle of its useful service life, generally between 1/3 and 2/3 RSL.
- Very Good – The pavement surface is at the beginning of its useful service life, generally greater than 2/3 RSL.

Rehabilitation Dictionary

Using the Condition Dictionary as a reference, a Rehabilitation Dictionary of available Preservation, Restoration and Reconstruction (PRR) activities can be defined. The following fields define PRR activities:

- Surface Type
- Condition
- Activity Name
- Cost per Lane Mile
- Average Life Extension
- Resulting Surface Type
- Additional Filter (such as limiting the AADT for a given activity)

By providing flexible interface to define PRR activities, the Forecaster becomes well suited for new technologies and practices, and additionally aids in understanding them prior to implementation. For example, the Forecaster could be used to analyze the sensitivity of ACP resurfacing costs, an aggressive Crack and Seat Overlay program for rigid pavements, or the adjustment in the AADT threshold for chip sealing ACP surfaces.

Prioritization Strategy Definition

The Prioritization Strategy defines which Preservation Units must be prioritized in conjunction with the PRR activities. The Forecaster follows a two-tier approach to prioritization. Tier 1 prioritization is based on the characteristics of the Preservation Unit (AADT, truck traffic, Functional Class, etc). Here is the current list of Tier 1 prioritization options currently available to the Forecaster:

- None
- Risk
- AADT
- Functional Class

- Dollars per Lane Mile Truck (LMT) - $/LMT (this is calculated as the Equivalent Uniform Annual Cost, or EUAC, divided by annual trucks)
- Reconstruction Mitigation ($/LMT)

Tier 2 prioritization is based on the Rehabilitation Dictionary, which allows the user to prioritize by activity. This allows activities to be prioritized according to EUAC, Reconstruction Mitigation, or some other strategy.

THE FORECASTING ALGORITHM

Once the Forecast Scenario has been defined, the Forecast can be run through the Forecast Algorithm, shown in Figure 1.

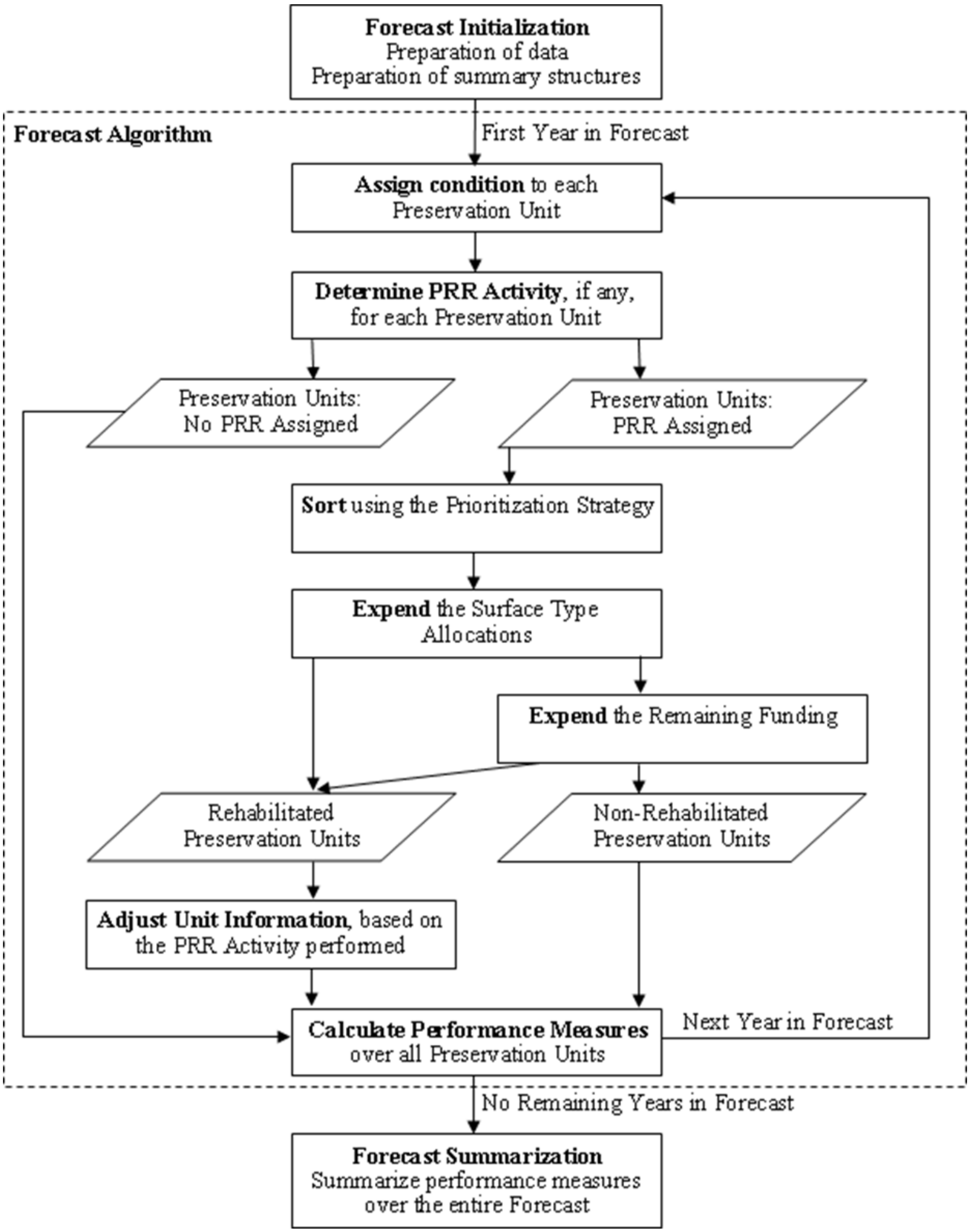

FIGURE 1 the Forecast Algorithm

PERFORMANCE MEASURES

For effective analysis of a forecast and effective comparison across forecasts, the Forecaster tracks and summarizes several performance measures including Condition, Deferred Preservation Liability, Remaining Service Life, Asset Sustainability Ratio, Risk and Equivalent Failure Factor. Figure 2 is a visual overview for how the Forecaster summarizes and presents these performance measures.

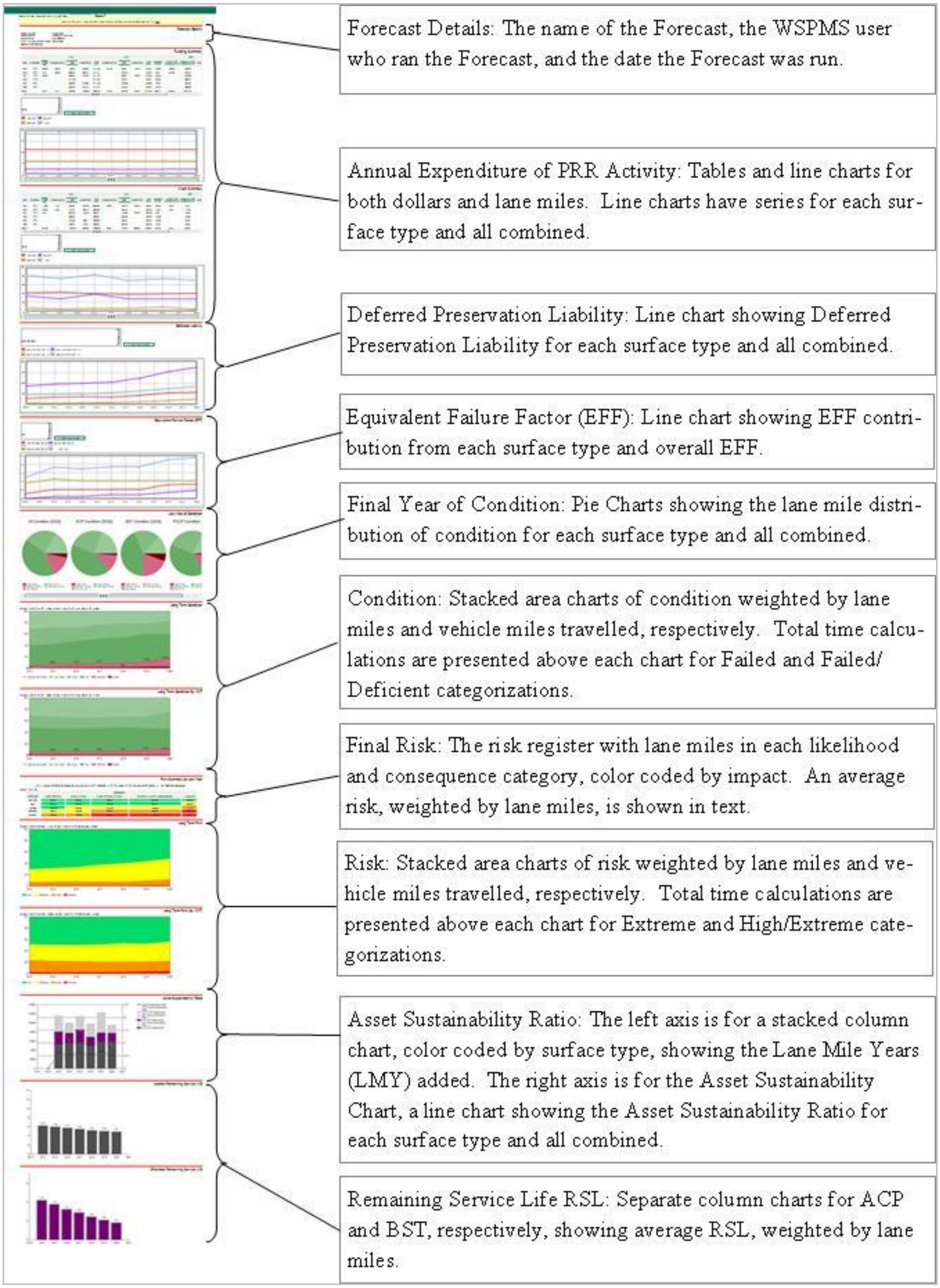

FIGURE 2 Summarization of performance measures as presented by the Forecaster.

A brief overview of each performance measure is detailed below, including how it is calculated, presented in the Forecaster and what the performance measure should be when a pavement network is performing at LLCC. Prior to each performance measure overview, it is useful to understand the weighting and presentation used across performance measures.

Weighting Performance Measures

Since network-wide performance measures are accumulations or averages of values calculated for individual sections, how the measure is accumulated or averaged is important. The two main ways that the Forecaster weights performance measures is by Lane Miles and Vehicle Miles Travelled (VMT). Using Lane Miles does a better job of explaining how all of the assets are performing as a group, while using VMT does a better job of explaining the impact of asset performance on the traveling public. For each performance measure, the Forecaster summarizes both VMT and Lane Miles to allow for the creation of accumulations and averages using one or both weights.

Presenting Performance Measures

The Forecaster presents performance measures using several different presentation methods including tables, line charts, bar charts, pie charts and stacked area charts. Pie charts are used to summarize information at a single point in the Forecast, usually at the end. The other presentation methods are used to convey information within each year and over the entire time frame of the Forecast. The Forecaster uses multiple presentation methods over the same performance measure. In addition, all of the tabular data generated by the Forecaster can optionally be downloaded and analyzed using a separate program, such as Microsoft Access or Microsoft Excel.

Percentage of Total Time Calculation

One analysis methodology is finding the area under the curve for a given value or group of values in a performance measure and comparing it as a percentage to the total area within the performance measure. This allows a quick analysis of how the particular indicator is being managed over the entire Forecast. For example, if two Forecasts both end up with 4% "Failed" roadways, this does not mean that both are equally valid. Assuming the first methodology gradually built up to 4% while the second method quickly reached 4% but then mitigated further Failed roadways, the first methodology might be more preferable because overall it had a lower amount of cumulative Lane Mile Years (LMY) of Failed roadways. Using the percent area under each Failed Curve would show slightly less than 4% for the first scenario and approximately 2% for the second scenario. An example is shown in Figure 3 for the Percentage of Total Time Calculation.

Annual Expenditure by PRR Activity

While technically not a performance measure, understanding how the Forecaster expended the funding between PRR activities is vital to understanding the behavior of performance measures. Annual expenditures are presented in two summary tables, one in dollars and the other in lane miles, for each PRR activity and year. A line chart also accompanies each table, with a line for the accumulated activities within each surface type and all surface types.

Condition

The Forecaster presents condition information in many ways. First, pie charts are presented for each surface type and for all combined, showing lane mile totals in each condition at the end of the Forecast. Second, stacked area charts weighted by both lane miles and VMT are presented. Last, for both stacked area charts, the percentage of time spent in Failed and time spent in Failed or Deficient condition are shown.

At LLCC, the percentage of Failed and Deficient roadways is 0.

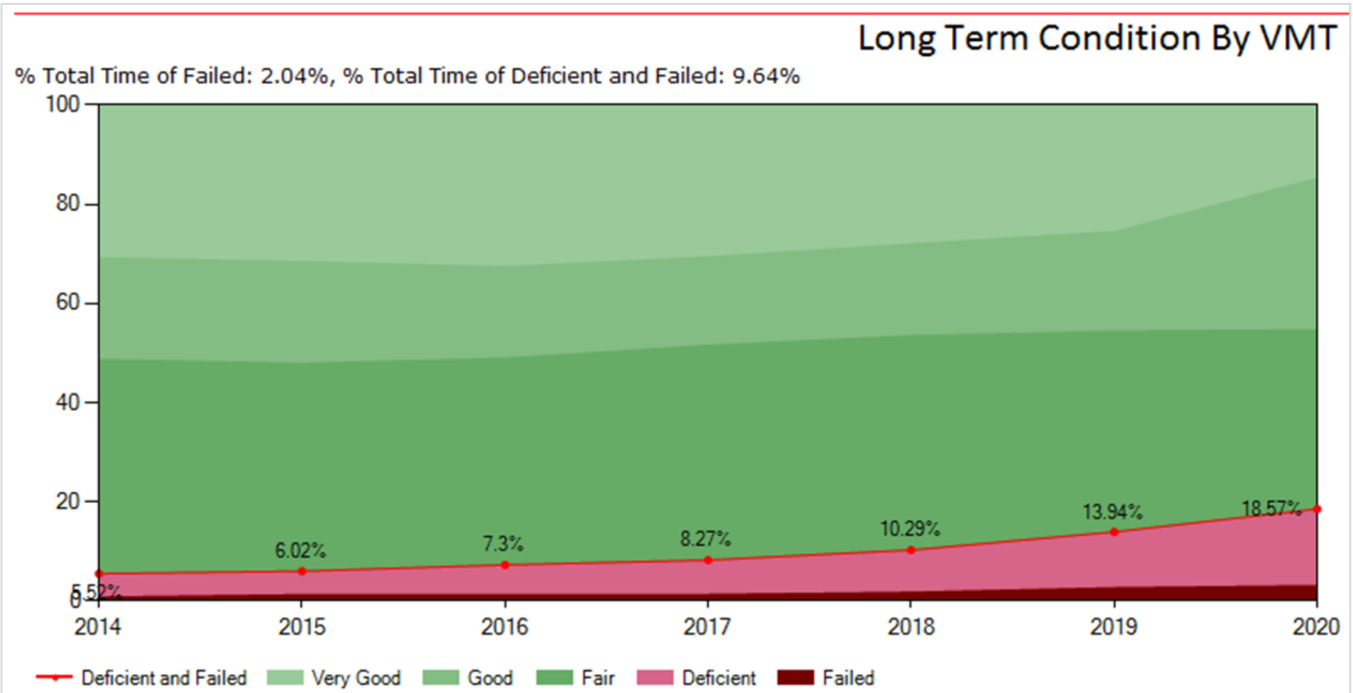

FIGURE 3 Example of stacked area chart (weighted by VMT) and percentage of time calculated, as shown in the Forecaster

Deferred Preservation Liability

Presenting the economic ramifications of missed preservation opportunities demonstrates the vital importance of asset management and proper funding. In the Forecaster, all PRR activities assigned by the Forecast Algorithm are defined as needed. Therefore, to calculate the liability, in dollars, of not performing these needed activities can be done by assuming cost of the PRR activity that will be assigned in the following year. This is called the Deferred Preservation Liability. The Forecaster presents the Deferred Preservation Liability with a line chart, with lines for each surface type and a line for all surface types combined.

At LLCC, the Deferred Preservation Liability is $0. It should also be noted that the Deferred Preservation Liability will grow exponentially during sustained underfunding, because reconstruction, due to the accumulation of reconstruction need.

Remaining Service Life (RSL)

Like condition, RSL is also ambiguous for pavement assets, since there can be a service life of the surface, of the entire structure, or between maintenance activities. The Remaining Service Indicator (RSI) has recently been suggested as alternative nomenclature to RSL *(2)*, with the desire that the RSI would be defined by activity and not a generalization about the pavement. However, since the WSPMS is geared towards a goal of planning LLCC activities, the RSL is calculated as the difference between a reference year and the expected year for an LLCC activity. LLCC activities that are past due are not further penalized for RSL when reported as a performance measure. Finally it should be noted that while a pavement with RSL 0 may be able to carry traffic, by definition it no longer meets an acceptable LOS.

Currently, the Forecaster presents RSL as separate column charts for ACP and chip seal surfaces. Since JPCP RSL combines multiple PRR activities, RSL becomes confusing, and therefore the Forecaster does not present it.

At LLCC, the average RSL is approximately half of the service life between the major LLCC activities. However, when allowing for the uneven distribution of pavement age, an individual year's RSL values may fluctuate between 40% and 60% of the service life at LLCC.

Asset Sustainability Ratio

The Asset Sustainability Ratio has gained recognition as a useful performance measure because it indicates the extent assets are being replenished relative to the rate they are being consumed *(3)*. In the case of WSPMS, Lane Mile Years (LMY) replenished is calculated per year as the product of lane miles of pavement with PRR activities and the number of years of expected Service Life added by the PRR activity. Pavement consumption is equal to the number of lane miles in the network, which for one year would be the LMY consumed. The Asset Sustainability Ratio is the ratio of LMY replenished to LMY consumed.

The Forecaster presents the Asset Sustainability Ratio as a combination stacked column and line chart. LMY replenished is shown as a column chart, stacked by surface type. The Asset Sustainability Ratio is shown as a line, with one line for each surface type and one for all combined. Separating out the Asset Sustainability Ratio for each surface type gives a good indicator for PRR activity distribution for each surface type sub-network.

At LLCC, the Asset Sustainability Ratio is close to 1. For similar reasons as RSL, the Asset Sustainability Ratio may fluctuate from 0.9 to 1.1 depending on the particular needs in a given year.

Risk

Risk is the first of two performance measures developed in conjunction with the Forecaster. Risk was necessary to develop because as asset management advances, risk increasingly is considered *(4)*, as evidenced with it being included in the recent federal legislation referred to as MAP-21 *(5)*. Since Asset Management is very broad, there are many types, scopes and contexts for risk. In fact, WSDOT already uses Risk Management for major projects and at the agency level. However, specifically quantified risk in the context of the WSPMS had not previously been done.

A new risk register was developed to convey the extra risk associated with deteriorated pavements. The risk being described is a generic negative traffic and vehicle user event and purposely left non-specific because analyzing a risk for a specific type of event (reduced speed limit, collisions, etc.) is too difficult to predict.

For the risk register, *likelihood* is defined using the Condition Dictionary, where roadways needing reconstruction are assigned a frequent likelihood while newly rehabilitated roadways are assigned a very rare likelihood (so failed roads are very likely to cause the negative event, and newly rehabilitated roads very unlikely). *Consequence* is defined by Functional

Classification. Figure 4 shows the numeric values (in parenthesis) assigned for both likelihood and consequence. *Impact* is defined as the product of the likelihood and consequence, with the following categorizations: 0 – 39: Low, 40 – 59: Moderate, 60 -79: High, 80 – 100: Extreme. Since the level of risk is calculated numerically, the overall risk within a pavement network can be defined as the weighted average of the individual risks (weighted by lane mile or VMT).

	Consequence				
Likelihood	(6) Major Collector	(7) Minor Arterial	(8) Other Principal Arterial	(9) Principal Arterial	(10) Interstate
Very Rare (2) [Very Good]	Low (12)	Low (14)	Low (16)	Low (18)	Low (20)
Rare (4) [Good]	Low (24)	Low (28)	Low (32)	Low (36)	Moderate (40)
Seldom (6) [Fair]	Low (36)	Moderate (42)	Moderate (48)	Moderate (54)	High (60)
Common (8) [Deficient]	Moderate (48)	Moderate (56)	High (64)	High (72)	Extreme (80)
Frequent (10) [Failed]	High (60)	High (70)	Extreme (80)	Extreme (90)	Extreme (100)

FIGURE 4 Risk Register used by the Forecaster

Similar to condition, the Forecaster uses several ways to present risk. First is a table similar to the risk register, showing the number of lane miles in each category. Second is the average risk, weighted by lane miles, of the system at the end of the forecast. Third is two stacked area charts, stacked by impact category, with one weighted by lane miles and the other weighted by VMT. Finally are calculations of the total percentage spent in Extreme and High/Extreme risk for each stacked area chart.

At LLCC, overall risk is categorized as Low and no pavements have a likelihood of Common or Frequent.

Equivalent Failure Factor (EFF)

Finally, the Equivalent Failure Factor (EFF) was also developed in conjunction with the Forecaster. The EFF is the ratio of the cost of reconstruction needs to the cost to reconstruct the entire pavement network (multiplied by 100 for convenience). The EFF is useful because it communicates network stability without specific dollar amounts, which tend to be controversial. The main use of it is to indicate when a pavement network has reached a point where there is as much reconstruction need as there is funding, which will be referred to as critical instability. In this event, the pavement manager would have to choose either to reconstruct high-risk roadways or allocate funding to more cost efficient preservation or restoration activities.

Since WSDOT fiscally operates using biennia, having to allocate one biennium worth of LLCC level funding was chosen as the indication of critical instability. For WSDOT, this corresponds to an EFF of ~4%. Please note that 4% is not constant across disparate pavement networks for two years, as the ratio will change depending on the difference between the cost of LLCC and total reconstruction. For WSDOT, however, effectively moving the EFF 4% would require large, unreasonable changes to this difference. For example, calculating the EFF of critical instability for the WSDOT network after 500 lane miles worth of crack and seat overlay (i.e. converting 500 miles from JPCP to ACP) only causes a 0.03 change in critical EFF. Therefore, WSDOT can confidently use the generality for the foreseeable future.

The Forecaster uses a line chart showing the overall EFF and also the contribution to the EFF by each surface type. Visually, this allows the user to see the final EFF and also the year that critical instability (EFF 4%) is reached, if at all.

At LLCC, the EFF is 0.

COMPARING FORECASTS

To allow WSDOT to develop the best prioritization methodology within the stated constrained funding scenario, a manual compilation comparing performance measures from over 30 different Forecasts was analyzed. All of the Forecasts were done for fiscal biennia 15-17, 17-19 and 19-21 (corresponding to construction years 15-16, 17-18, and 19-20, respectively). Additionally, the effects of the 13-15 biennium were accounted for within the Preservation Units. The Forecasts differentiated by the amount of funding, the allocation of funding among the surface types and prioritization strategies.

Investment Levels

Five different funding scenarios were analyzed:

1) *30% LLCC* –Based on the amount of preservation funding in one severely under-funded scenario; approximately 30% of what LLCC requires.
2) *50% LLCC* – Scenario #1 + $100M per biennium.
3) *LLCC Funding* – The amount of funding LLCC indicates for WSDOT, without regard to current state or age distribution, as would be calculated from the Annual LLCC equation.
4) *Unconstrained Funding* – Because of the age of the WSDOT JPCP network and the existing backlog of flexible preservation needs, an unconstrained scenario would require more funding than simple LLCC calculation indicates.
5) *No Funding* – This is useful to understand the limits of what the Forecaster would predict for each performance measure without any PRR activities.

Surface Type Allocations

There were two basic surface type allocations used:

1) *None* – Funding was allocated solely on the Prioritization Strategy.
2) *60-10-30* – Funding was allocated 60% ACP, 10% chip seal and 30% JPCP. This particular balance was used because it approximately follows a distribution between the distribution of truck traffic and the distribution of funds at LLCC. Consequently, it showed a balanced approach for all performance measures.

Prioritization Strategies

As mentioned in section on Prioritization Strategy Definition, there are several possible prioritization strategies available to the Forecaster. A few of the most relevant, in terms of current Agency use, prioritization strategies were analyzed:

1) *LLCC* – Prioritized by EUAC, from lowest EUAC to highest EUAC.
2) *Reconstruction Mitigation (LLCC)* – Reconstruction mitigation gives the highest priority to roadways about to move from Deficient to Failed. Within this group PRR activities are prioritized by LLCC. Any remaining funds are then prioritized by LLCC.
3) *$/LMT* – Prioritized by $/LMT, from lowest to highest. $/LMT is calculated by dividing the EUAC by annual trucks, giving a good indicator for activities that are the best buy regarding freight traffic (which is also highly correlated to overall traffic).
4) *Reconstruction Mitigation ($/LMT)* – Roadways about to go from Deficient to Failed were given the highest priority, and within this first tier they were prioritized by $/LMT. Any remaining funds are then allocated using $/LMT prioritization.

Results

Including specific results for over 30 different Forecasts for the several different performance measures is not feasible within this paper. Instead, the most important trends are presented.

Comparison of Investment Levels

Unsurprisingly, as investment levels increase, all of the performance measures improve towards the target value indicated at LLCC. Most importantly, the total investment plus the deferred liability, which would be the overall eventual agency cost after 6 years, is reduced as investment approaches LLCC levels. Figure 5 shows that after the 6 year period analyzed, it will cost approximately $500M more when invested at 50% LLCC and $900M more when invested at 30% LLCC. This affirms the phrase “good roads cost less”, originally used by the Utah DOT in 1977 *(6)*.

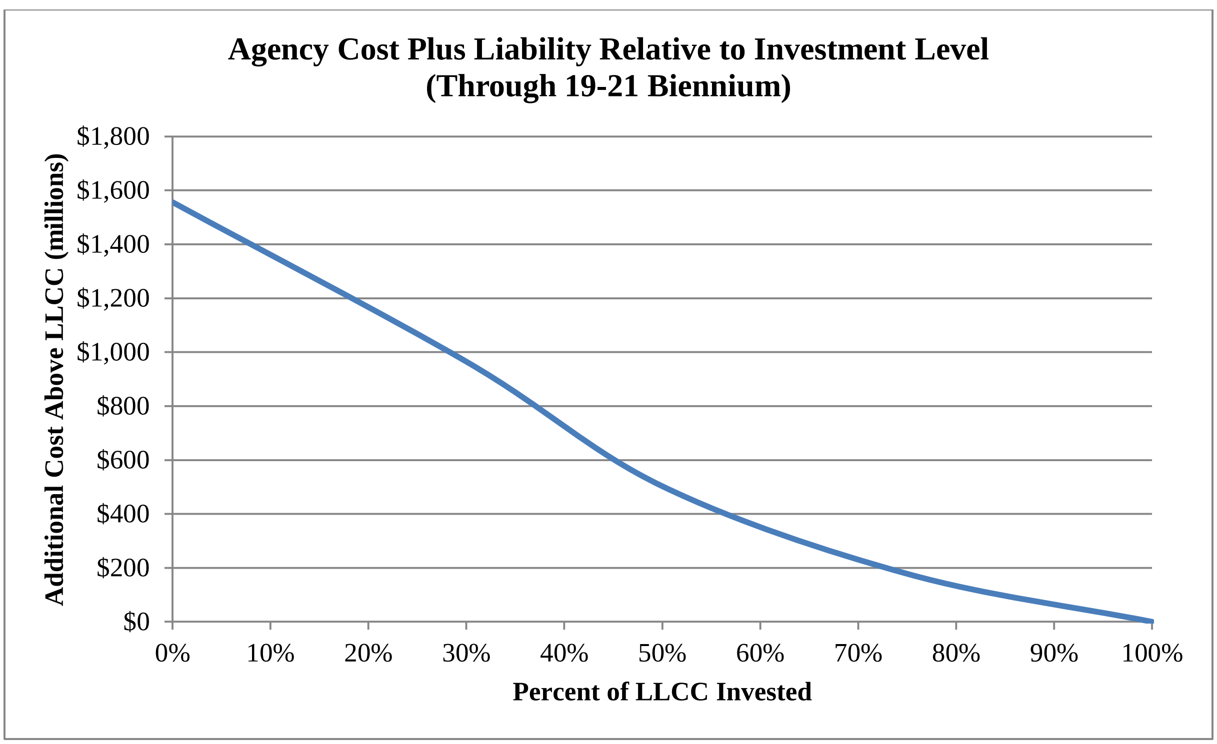

FIGURE 5 WSPMS Forecaster Results Showing the additional Liability based on Investment Level, using a 60-10-30 surface allocation and Reconstruction Mitigation ($/LMT) prioritization strategy

Finally, it should be noted that Figure 5 only references the funding differences using a 60-10-30 surface type allocation in conjunction with a Reconstruction Mitigation ($/LMT) prioritization strategy. Other combinations could raise the eventual agency cost to lower risk in the short term or lower eventual agency cost by raising risk in the short term, which is explained in the following sections. **The trend is always the same, however, for all prioritization strategies and allocations; funding at less than LLCC will always eventually cost more.**

Comparison of Prioritization Strategies

Each prioritization strategy is designed to optimize a specific performance measure, which can be reasonably expected. Here is a list of rules to keep in mind when considering a Prioritization Strategy:

- LLCC Prioritization will favor chip seal, followed by ACP. JPCP will be a distant third, as demonstrated in the 50% LLCC Forecast, which had $0 JPCP expenditures when LLCC Prioritization is used.
- Reconstruction Mitigation (LLCC) will favor chip seal, followed by ACP and JPCP for similar reasons to LLCC Prioritization.
- $/LMT favors JPCP and ACP, with chip seal a distant third. The bias against chip seal is not quite as strong as the bias against JPCP in LLCC Prioritization, as shown with a small amount of chip seal expenditures at 50% LLCC Funding.
- For 50% LLCC and 30% LLCC funding, LLCC Prioritization does the best job at minimizing Deferred Liability. As LLCC Funding is approached, Deferred Liability is controlled by mitigating reconstruction and Reconstruction Mitigation (LLCC) is the best at minimizing it.
- The final percentage of roadways that are Deficient or Failed, weighted by lane miles, is best minimized by LLCC Prioritization. When weighted by VMT, this percentage is best minimized by $/LMT Prioritization.
- The final percentage of roadways that are in High or Extreme risk, weighted by lane miles, is best minimized by LLCC Prioritization. In contrast, when weighted by VMT, it is best minimized by $/LMT.
- The total time spent in Extreme risk, weighted by lane miles, is best minimized by Reconstruction Mitigation (LLCC). When weighted by VMT, it is best minimized by $/LMT.
- The time until EFF 4, or critical instability, is maximized when using Reconstruction Mitigation (LLCC).
- At 50% and 30% LLCC Funding, all Prioritization Strategies reached an EFF 4 within the Forecast time frame, ranging from early 2017 (30% LLCC Funding using LLCC Prioritization) to late 2019 (50% LLCC Funding using Reconstruction Mitigation (LLCC) prioritization).

Comparison of Surface Type Allocations

As evidenced in the results from comparing prioritization strategies, each surface type is best suited at optimizing different performance measures. Consequently, the 60-10-30 surface type allocation forced a balance and realistic approach between prioritization strategies. For example, when comparing Reconstruction Mitigation (LLCC) with and without a 60-10-30 surface type allocation, adding the allocation results in a marginal (2.7%) increase in Deferred Liability, but substantial reductions in total time in extreme risk because of immediate application towards JPCP pavements, which tend towards higher risk.

Recommended Prioritization Methodology for WSDOT

Based on the predicted performance measure outcomes in the Forecaster and keeping pavement management objectives in mind, it is recommended that WSDOT use the 60% ACP, 10% chip seal and 30% JPCP surface type allocation in conjunction with a Reconstruction Mitigation ($/LMT) prioritization strategy. This allows for the proper short term pavement management goals of keeping pavement network safe, functional and efficient, without immediately sacrificing long term goals of protecting the infrastructure investment and economic sustainability.

Implementation of the recommendation would fit well within the existing prioritization process at WSDOT, which was used to prioritize preservation projects for the 13-15 biennium. The current prioritization separated JPCP projects and flexible pavement (ACP and chip seal) projects. For JPCP, generally "triage" (panel replacement and diamond grinding) projects were funded for sections deemed too critical to wait. The remaining funding was prioritized between flexible projects using a Reconstruction Mitigation ($/LMT) strategy. To apply the recommendation in this paper for the 15-17 biennium, the main difference would be to prioritize ACP and chip seal projects separately and start the process with 60% ACP, 10% chip seal and 30% JPCP funding distribution.

It also should be noted that the strategy is applicable at the network level. Separate policies and procedures are in place to make sure that the most cost-effective projects are proposed to be prioritized. If changes to the scope of a project are changed as part of the prioritization process to make a project more cost-effective, its information would be updated and reprioritized.

Finally, there is no sub-optimal solution at 50% LLCC or 30% LLCC that avoids critical instability, meaning that new preservation revenues are mandatory to maintain the required LOS. Additionally, substantial gains cannot be made by sacrificing lower volume roadways, because making significant strides in risk and avoiding critical instability can only be done with proper investment in the highest cost roadways.

CONCLUSIONS

The WSPMS has long been used at WSDOT to help implement LLCC. However, it has never been used to understand the consequences of a massive funding shortfall, as is the case in the current economic climate. In response to this challenge, the Forecaster was developed within the WSPMS to find the best methodology to balance the short and long term pavement management objectives of keeping the system safe and efficient, protecting the infrastructure investment, and managing it in a cost-effective manner. To further aid in the analysis, several performance measures were analyzed from multiple vantage points.

The early results from the Forecaster are very promising, and it will become an integral part of the WSPMS. The success of the Forecaster is attributed to a flexible interface for creating a Forecast Scenario and a robust set of performance measures analyzed in many different ways. Over 30 different Forecast Scenarios were analyzed using the Forecaster, using different funding levels, surface type allocations and prioritization strategies. Key patterns and strategies emerged when comparing the performance measures from them.

After comparing the Forecaster results from these Forecast Scenarios, it is recommended for WSDOT to use a three-pronged methodology to balance and optimize the pavement management objectives in the current constrained economic climate. First, a 60-10-30 surface allocation (60% ACP, 10% chip seal and 30% JPCP) will be targeted because it creates balance between the competing pavement management objectives. Second, mitigating reconstruction activities will be prioritized the highest because it extends the timeframe of sustainability recovery while reducing hot spots of risk. Finally, activities will be prioritized using Dollars per Lane Mile Truck ($/LMT - the EUAC divided by annual trucks), because it provides the best methodology to support efficient freight movement.

DISCLAIMER

This paper contains the opinions and viewpoints of the authors alone, and does not constitute a policy or standard of the Washington State Department of Transportation.

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